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LIFE HISTORY, ABUNDANCE, AND DISTRIBUTION OF MOAPA DACE (*MOAPA CORIACEA*)

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ABSTRACT.—Moapa dace (*Moapa coriacea*) is a federally listed endangered fish endemic to the spring-fed headwaters of the Muddy River, Clark County, Nevada. Species life history, abundance, and distribution were studied from March 1984 to January 1989. Reproduction, which was observed year-round, peaked in spring and was lowest in fall. It occurred in headwater tributaries of the Muddy River, within 150 m of warm water spring discharge in water temperatures ranging from 30 to 32 C. Females matured between 41 and 45 mm in fork length (FL). Egg abundance increased with female size (r^2 = .93); counts ranged from 60 for a 45-mm-FL female to 772 for one 90-mm FL. The oldest of eight fish, aged by the opercle method, was a 90-mm-FL, 4+-year-old female. Adults are omnivorous but tended toward carnivory; 75% of matter by volume consumed was invertebrates and 25% plants and detritus. Fish size was generally commensurate with flow, the largest fish occurring in the greatest flow. Adults were near bottom, in focal velocities ranging from 0 to 55 cm/s. Juveniles occupied a narrower range of depths and velocities than adults, and larvae occupied slack water. From December 1984 to September 1987, the total adult population ranged from 2600 to 2800. Although these numbers are higher than previously believed for Moapa dace, they are still sufficiently low to warrant its endangered status. The dependency of Moapa dace's different life history stages to various areas and habitat types of the Warm Springs area suggests that all remaining habitat is necessary for their survival.

Key words: Moapa coriacea, *Moapa dace, life history, reproduction biology, fecundity, age-growth, food habits, habitat use, body size, Muddy River, Nevada.*

The Moapa dace (*Moapa coriacea*) is a thermophilic minnow endemic to the Muddy River system, Clark County, Nevada. First collected in 1938, it has historically been relegated to the headwater area where the Muddy River originates from a series of warm springs (Hubbs and Miller 1948). La Rivers (1962) called the Moapa dace and its coinhabitant, Moapa White River springfish (*Crenichthys baileyi moapae*), thermal endemics because of their apparent affinity for warm water. Rarely exceeding 12 cm in fork length (FL), Moapa dace have morphological similarities to roundtail chub (*Gila robusta*) and speckled dace (*Rhinichthys osculus*), which also inhabit the Muddy River (Hubbs and Miller 1948). They are more similar, however, to the genus *Agosia*, which occurs in other lower Colorado River drainages; the two genera are speculated to have a common ancestor (Hubbs and Miller 1948). Moapa dace are distinguished by small embedded scales and a bright black spot at the base of the caudal fin.

Little was known of Moapa dace life history prior to this study. La Rivers (1962) identified them as methodical schoolers; a cursory gut examination by him indicated that they foraged primarily on arthropods and some vegetative matter. In a systematic sampling effort, Deacon and Bradley (1972) collected Moapa dace in 28–30 C water; one specimen was collected in 19.5 C water. Within the confines of its limited distribution, Moapa dace have been captured in a variety of habitats, including spring pools and slow- to fast-moving water, and in association with various substrates and submergent vegetation (Hubbs and Miller 1948).

Past ichthyofaunal surveys suggested a declining Moapa dace population (Deacon and Bradley 1972, Cross 1976). These surveys were qualitative and produced neither an estimate of the number of dace remaining nor the relative population decrease between surveys. Ono et al. (1984) thought that only several hundred Moapa dace persisted and that their distribution had been further restricted within the already limited historic habitat, confining them to the

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main stem of the upper Muddy River and a semi-isolated headwater spring system about 130 m long. The purpose of this study is to expand information on Moapa dace life history, abundance, and distribution. Life history information includes reproductive biology, habitat use, food habits, and age and growth.

STUDY AREA

The Muddy River is at the northern edge of the Mohave Desert, where average annual precipitation is 15 cm usually in the form of rain. Carpenter (1915) described historic terrestrial vegetation which included greasewood (*Sarcobatus vermiculatus*), shadscale (*Atriplex confertifolia*), creosote bush (*Larrea tridentata*), and mesquite (*Prosopis* sp.). Stream banks were lined with willows (*Salix* sp.), screw-bean (*Prosopis pubescens*), cottonwood (*Populus* sp.), and mesquite (Carpenter 1915, Harrington 1930). Prior to the completion of Hoover Dam (aka Boulder Dam) in 1935, the Muddy (aka Moapa) River was about 48 km long and discharged into the Virgin River, which joined the Colorado River (Hubbs and Miller 1948). Today, it is about 40 km long and discharges into the Overton arm of Lake Mead (Fig. 1). Source springs of the Muddy River probably originate from Paleozoic carbonate rocks (Garside and Schilling 1979) and occur within a 2-km radius. As is typical of warm springs, the water is relatively rich in minerals. Garside and Schilling (1979) list sodium and calcium as predominant cations, and carbonate and sulfate as predominant anions; total dissolved solids were 854 ppm and pH was 7.7. Water emerges at 32 C and cools and increases in turbidity downstream (Cross 1976). Although spring discharge is relatively constant at about 1.1 m^3/s, the Muddy River flow fluctuates because of rain, agricultural diversions, evaporation, and transpiration (Eakin 1964). The headwater region, the historic range of the Moapa dace, is known as the Warm Springs area (Fig. 1). During our study the area was used primarily for agriculture, and up to 0.25 m^3/s of river discharge was being diverted to irrigate alfalfa, barley, and pasture. Spring outflows had been channelized, and several were converted into irrigation ditches, some lined with concrete. Earthen tributary channels had scant to thick riparian corridors of fan palm (*Washingtonia filifera*), tamarisk (*Tamarisk* sp.), ash trees (*Frazinus* sp.), and arrow weed (*Pluchea sericea*). Two nonnative fishes successfully established in the Warm Springs area: mosquitofish (*Gambusia affinis*), present when Moapa dace were discovered in 1938 (Hubbs and Miller 1948), and shortfin molly (*Poecilia mexicana*), introduced in the early 1960s (Hubbs and Deacon 1964). Besides Moapa dace and springfish, roundtail chub and speckled dace are the only native fishes occurring within the Warm Springs area, but they are rare and in greater abundance downstream (Cross 1976, Deacon and Bradley 1972).

In 1979 the Moapa National Wildlife Refuge (NWR) was established in historic habitat at the southern edge of the Warm Springs area for the preservation and perpetuation of the Moapa dace (Fig. 1). The refuge stream originates from five small springs occurring in a radius of 70 m and having a cumulative discharge of abut 0.09 m^3/s (Fig. 2). Fan palms are the predominant riparian vegetation. In 1984 Moapa dace larvae and adults were reintroduced into the upper Refuge Stream, and by January 1986 there was a stable reproductive population of 120 adults (authors, unpublished data). They were isolated by a 75-cm-high waterfall. Springfish were the only other fish present, and they were abundant.

MATERIALS AND METHODS

REPRODUCTIVE BIOLOGY.—Among our objectives was to quantify duration of the reproductive period and the season of peak larvae recruitment. To this end, a segment of the upper Refuge Steam system was snorkeled at 30- to 90-day intervals from February 1986 to January 1989 and larvae were enumerated (Fig. 2). This is the area in which virtually all reproduction on the Moapa NWR occurred. Dace 7–15 mm TL were considered larvae. This range approximates the proto- to metalarvae stages of the similar-sized speckled dace (Snyder 1981). Snorkeling enabled us to locate reproduction sites in the headwater Muddy River system and to determine the abundance and distribution of adult Moapa dace as well as to quantify habitat use for all life stages. Areas with larvae close to swim-up size (about 7 mm TL) were considered reproduction sites. Fish used for food habit analysis and aging were also used to determine fecundity.

HABITAT USE.—We defined habitat use in terms of stream depth and velocity at foraging sites and at suspected spawning areas. Depth measurements included focal and total, while

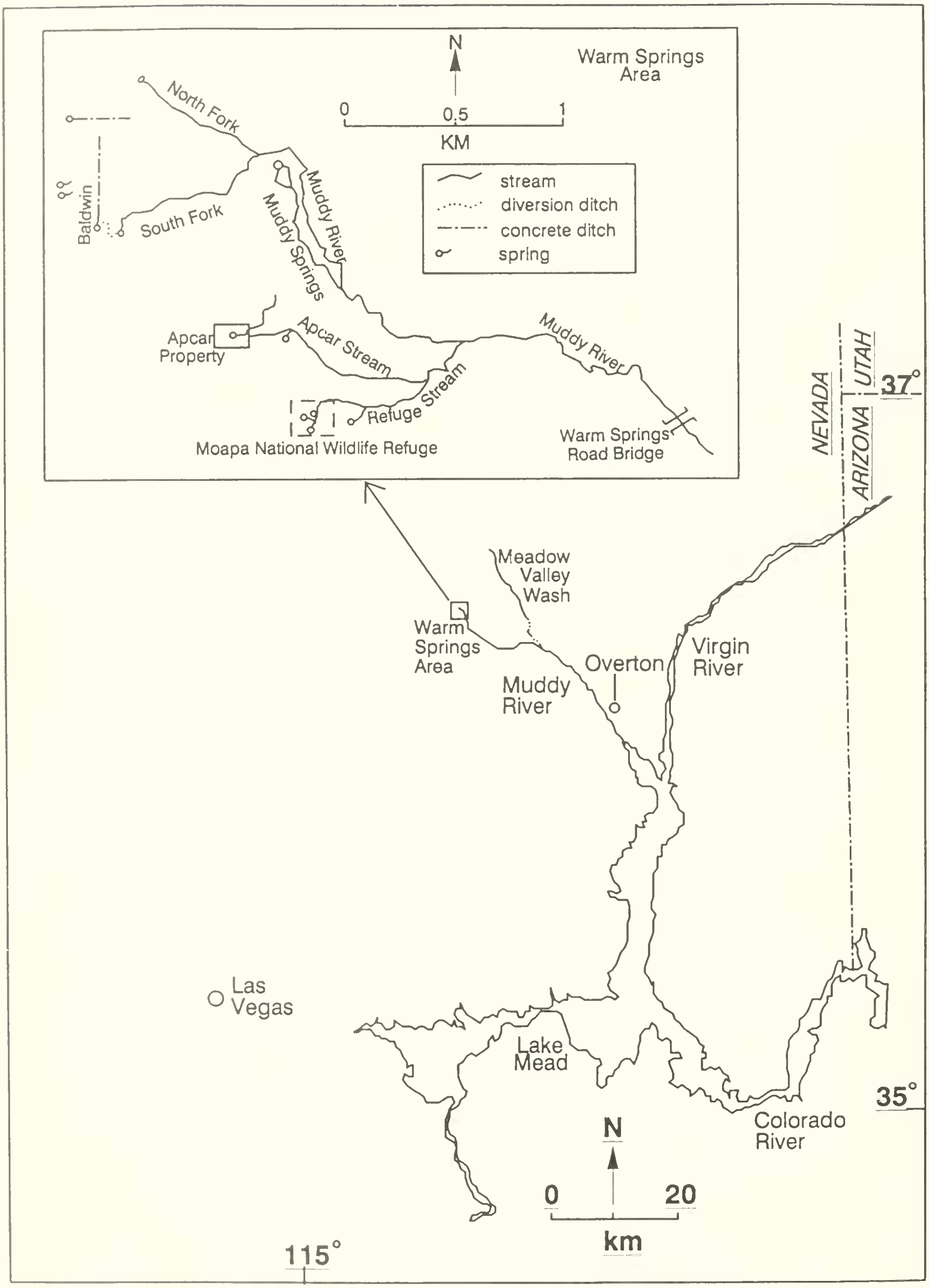

Fig. 1. Map showing relationship of the Muddy to the Virgin River and Lake Mead, Nevada, and relationship of the Warm Springs area to the Muddy River (below). Warm Springs area or headwaters of the Muddy River showing tributary streams to the upper Muddy River and relationship of the Moapa National Wildlife Refuge (above).

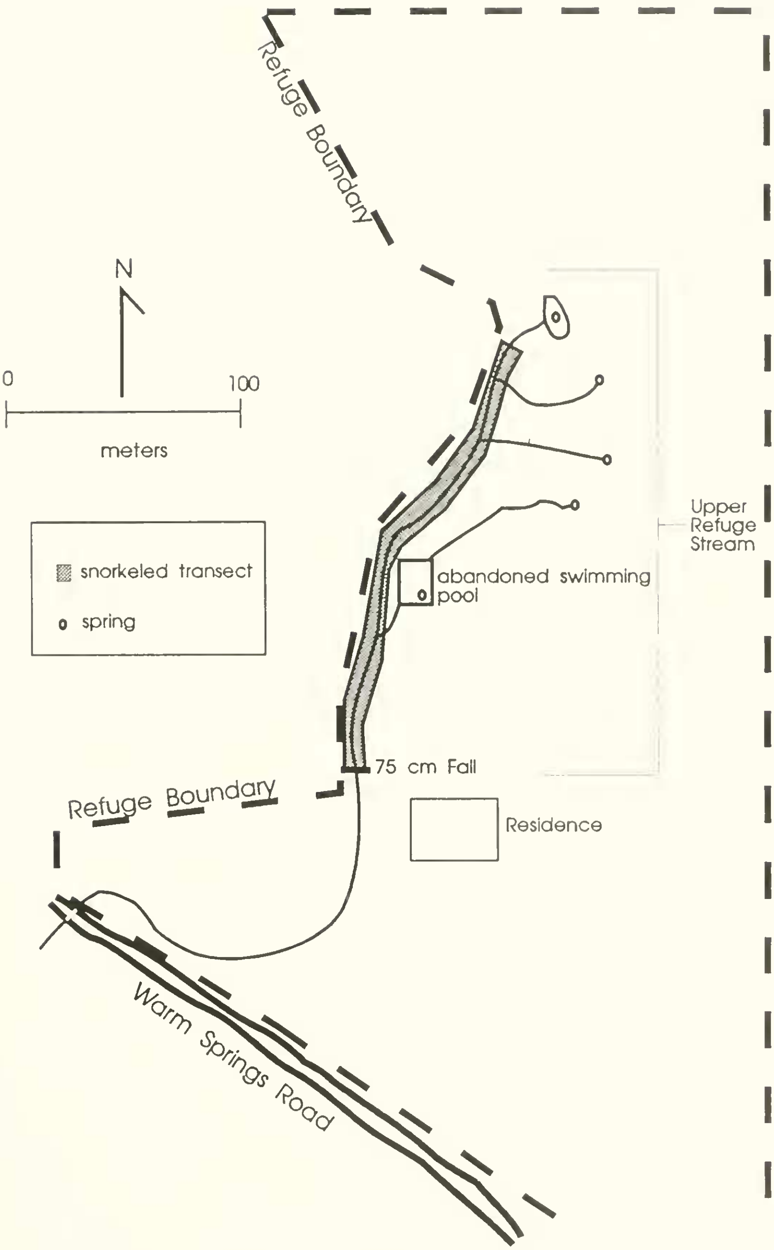

Fig. 2. Map of Moapa National Wildlife Refuge; shaded site indicates the reach of the upper Refuge Stream where larvae snorkel counts were made from February 1986 to January 1989.

velocity measurements included focal and mean water column, as prescribed by Bovee (1986). Dissolved oxygen and temperature were also measured. Fish were located using mask and snorkel. A Marsh and McBirney model 201D digital flow meter mounted on a calibrated rod was used to measure depth and velocity, and a Yellow Springs Instrument model 57 dissolved oxygen meter for temperature and dissolved oxygen. Sampling occurred from 1984 to 1986. Adult habitat was also defined by contrasting body size with quantity of stream flow; it was our subjective evaluation that larger fish were inhabiting larger water volumes. We tested this

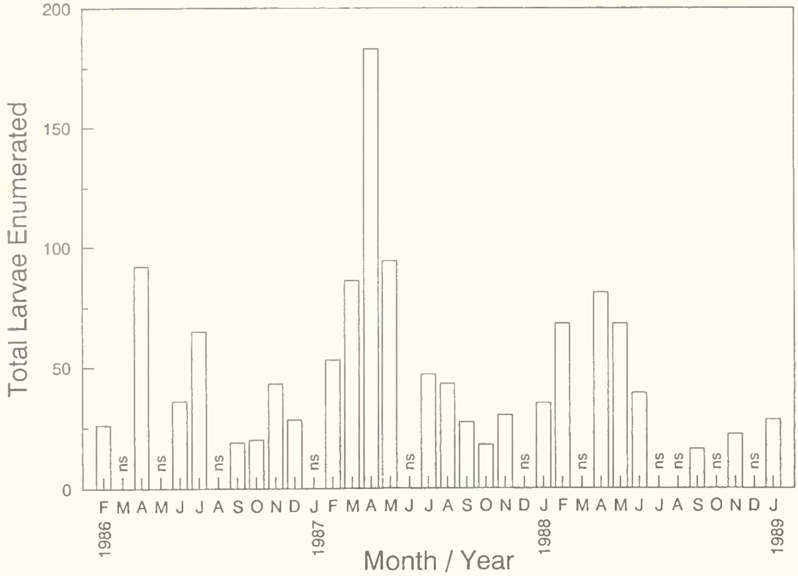

Fig. 3. Abundance of Moapa dace larvae from February 1986 to January 1989 in the Muddy River system on the Moapa National Wildlife Refuge, Nevada. Bars represent a single day's count for the month. NS indicates not sampled.

hypothesis in the summer of 1986 when samples of adults were minnow-trapped from the Muddy River, Muddy Spring Stream, Refuge Stream, and Apcar Stream and their length frequencies compared. Discharge for each stream was measured using standard U.S. Geological Survey methods (Rantz et al. 1982) near each fish sample. A one-way factorial ANOVA was used to test whether there was a significant difference between length frequency among fishes and different water volumes.

AGE AND GROWTH.—The opercle bone was used for estimating age as described by Casselman (1974). Eight specimens, collected in summer 1985 and 1986, were aged. Flesh was scraped with a scalpel and the bone allowed to dry. Glycerin was used to highlight the more transparent region of the bone, which was assumed to have the greatest calcium concentration and to have been formed in the winter when food is scarce. The more opaque region signifies greater concentration of protein associated with growth (Casselman 1974).

FOOD HABIT.—Food habit analyses were made from 10 Moapa dace taken 9–11 November 1984 from each of three upper Muddy River tributaries (Apcar, South Fork, and Muddy Spring). They were captured by seining and with unbaited minnow traps fished no longer than 10 minutes. Ranging from 42 to 71 mm FL, they were preserved in 10% formalin solution. Contents in the anterior third of the gut were examined using a dissecting microscope and quantified by frequency of occurrence (Windell 1971) and by percent composition (Hynes 1950).

ABUNDANCE AND DISTRIBUTION.—The abundance and distribution of adult Moapa dace (>40 mm FL) were determined by snorkeling the upper Muddy River system beginning from 200 m downstream of Warm Springs Road bridge (Fig. 1). Except for 1984, the surveys included 5.3 km of the upper Muddy River and 7.5 km of its spring-fed tributaries (Refuge Stream system, Apcar Stream, Muddy Spring, South Fork, and North Fork). In 1984 the survey area was the same except that only the upper 130 m of the Apcar Stream was snorkeled rather than its entire stream length. Snorkeling was conducted over periods of four to six days when turbidity was low (between 1.4 and 5.0 NTU) because no agricultural return flows were entering the stream. Counts were made 6–10 December 1984, 6–10 June 1986, and 16–22 September 1987. Each observer enumerated Moapa dace twice at three areas of relatively high concentrations (30–60 fish), and the range of results was then calculated. These sites were chosen because the greatest variation among observers was expected among them. For the three sites, variation was less than 15% in counts

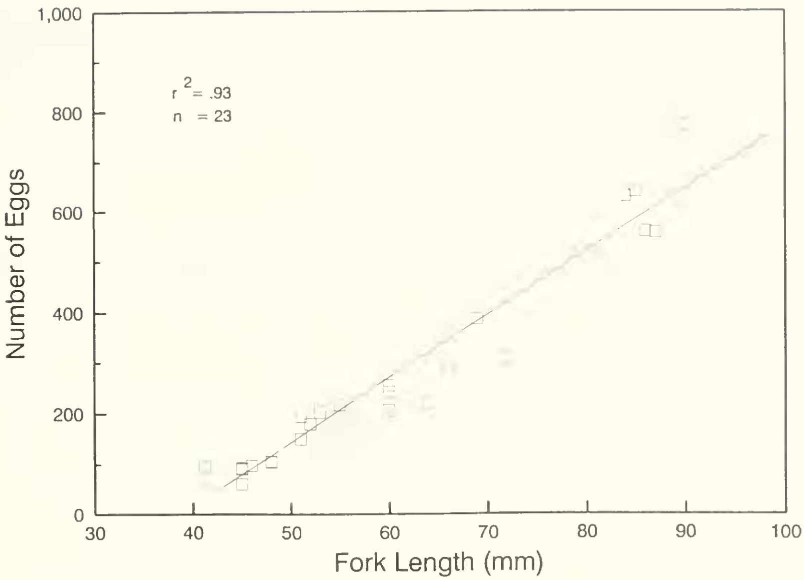

Fig. 4. Moapa dace fecundity as a function of fork length.

between individuals; thus, we conservatively estimated a 15% variation in our population counts.

RESULTS AND DISCUSSION

Reproductive Biology

Moapa dace larvae were found year-round, indicating year-round reproduction. On the Moapa NWR peak larval recruitment was in spring, the low in autumn (Fig. 3). Fish at other reproductive sites in the Warm Springs area exhibited this same general trend. Seasonal fluctuation in larval recruitment was probably linked to availability of food. In the upper Muddy River system the abundance of benthic and drifting invertebrates is much lower in winter than in spring (Scoppettone, unpublished data). Naiman (1976) documented substantial seasonal fluctuation in primary productivity in another southwestern warm springs where production is lowest in winter; presumably most invertebrate population fluctuates with primary production.

Recently emerged larvae were found within 150 m of spring discharge over sandy silt bottoms in temperatures of 30–32 C and dissolved oxygen of 3.8–7.3 mg/L. Whether spawning occurs only at these headwater sites or is successful only at these sites is unknown. Visual cues such as sexual dichromatism, pronounced male spawning tubercles, or overtly gravid females were not readily apparent, and spawning was not observed during our study. However, we indirectly identified and quantified spawning habitat. The presence of hundreds of protolarvae in a concrete irrigation channel immediately downstream of the Baldwin springhead (Fig. 1) indicated that reproduction had taken place. Progenitors apparently came from the South Fork, entering Baldwin Spring outflow through a diversion channel (Fig. 1). The concrete irrigation channel had homogeneous water depth and velocity, and substrate was sandy silt. Several depressions in the sand were similar to "redds" described for longfin dace (*Agosia chrysogaster*; Minckley and Willard 1971). Depth and velocity at the suspected redds were representative of the outflow channel and similar to other suspected spawning areas in the Warm Springs area. Depth ranged from 15.0 to 19.0 cm, near-bed velocities from 3.7 to 7.6 cm/sec, and mean water column velocity from 15.2 to 18.3 cm/sec.

Similar to the longfin dace, which reproduces during much of the year (Kepner 1982), eggs in the skein of Moapa dace were in different stages of development. All visible eggs were counted, but because they are intermittently deposited and develop throughout a given year, our counts do not represent absolute annual fecundity. However, egg production increased with fish size (r^2 = .93, n = 25; Fig. 4). Counts

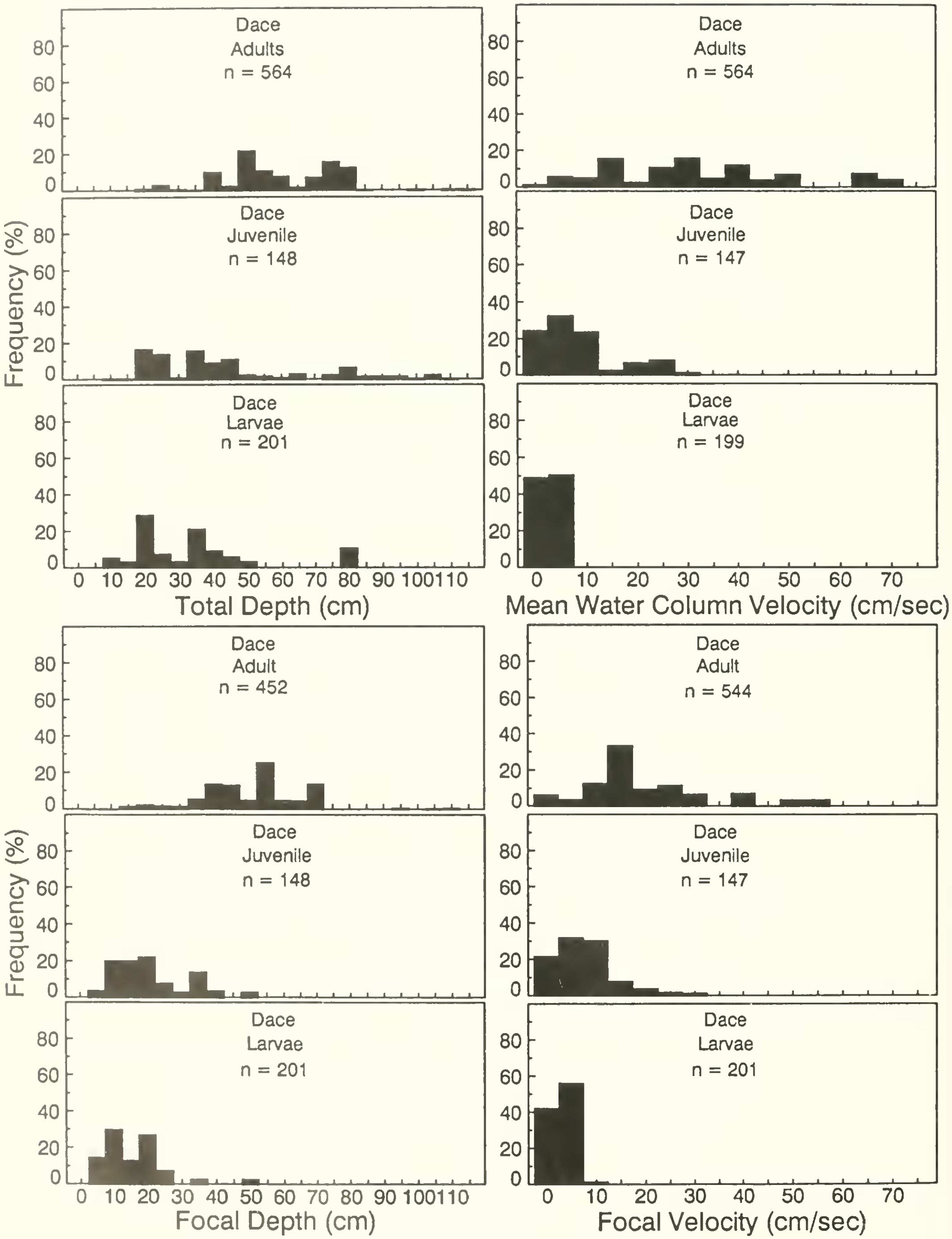

Fig. 5. Mean water column and focal point velocities, total depth, and focal point depth used by Moapa dace adults, juveniles, and larvae in the upper Muddy River system (Warm Springs area), Nevada, 1984 through 1986.

TABLE 1. Fork length, sex, and estimated age of eight Moapa dace collected from the upper Muddy River system, Nevada, in 1985 and 1986. Age was determined by the opercle method.

FL (mm)	Sex	Collection date	Age
45	Unknown	4/86	0+
55	Unknown	7/86	1+
61	Unknown	7/86	1+
67	Female	4/86	2+
69	Female	04/22/86	2+
77	Unknown	10/09/85	3+
80	Unknown	10/11/85	3+
90	Female	10/08/85	4+

ranged from 60 in a 45-mm-FL individual to 772 in a 90-mm-FL dace. Eggs were just developing in a 41-mm-FL female and were mature in a 45-mm-FL fish, suggesting that females mature at lengths in this range.

Habitat Use

Again, Moapa dace larvae were found exclusively in the upper reaches of spring-fed tributaries, while juveniles occurred primarily in tributaries but were more far-ranging. Adults were present in tributaries and in the main river, with larger fish generally found in the larger water volumes. There were significant differences in length frequencies among adults from different water volumes ($p \leq .006$). In the Muddy River, in a flow of about 0.50 m^3/s, mean FL was 73 mm (n = 78, SD = 16 mm); Muddy Spring had a flow of 0.20 m^3/s, and the mean FL was 64 mm (n = 72, SD = 14 mm); the Refuge Stream flowed at 0.17 m^3/s, and mean FL was 56 mm (n = 64, SD = 8 mm); the Apcar Stream flowed at 0.06 m^3/s, and mean FL was 51 mm (n = 89, SD = 5 mm).

Larvae occurred and fed in the mid- to upper region of the column. They were found most frequently in zero water velocity (Fig. 5). As size increased, individuals tended to occupy faster water and occur lower in the water column. Juvenile Moapa dace occupied focal and mean water column velocities ranging from 0 to 46 cm/s. Adults were found in a wide range of water depths and velocities, but they tended to orient at the bottom in low to moderate current. Water column depth ranged from 15 to 113 cm and focal point depth from 9 to 107 cm. Mean water column velocity ranged from 2 to 77 cm/s and focal point velocity from 0 to 55 cm/s. Water temperatures within adult habitats ranged from 27 to 32 C and dissolved oxygen from 3.5 to 8.4 mg/L.

TABLE 2. Food items ingested by 21 Moapa dace by percent composition (Hynes 1950) and percent frequency of occurrence (Windell 1971). Nine other guts examined were empty.

Food items	% composition	% of occurrence
GASTROPODA		
Tyronia clathrata	1.1	4.8
OLIGOCHAETE	27.0	23.8
AMPHIPODA		
Hyallela azteca	1.7	9.5
HEMIPTERA		
Pelocoris shoshone	4.5	4.8
HOMOPTERA		
Aphiidae	9.0	4.8
TRICHOPTERA		
Dolophilodes	5.1	9.5
Nectopsyche	4.5	9.5
LEPIDOPTERA		
Paragyractis	4.5	9.5
COLEOPTERA		
Stenelmis calida	1.1	4.8
Dytiscidae (larvae)	9.0	4.8
DIPTERA		
Chironomidae	4.5	4.8
Unidentified insect parts	3.3	9.5
Filamentous algae	18.5	42.3
Vascular plants	3.4	9.5
Detritus	2.8	14.3

Age Growth

Annulus formation is typically associated with an annual period of slower growth caused by seasonal changes in environmental conditions such as temperature or food resources (Tesch 1971). Although seasonal water temperatures do not change substantially in the Warm Springs area, there is an apparent reduction of potential food during the winter (Scoppettone, unpublished data). We were unsuccessful in aging Moapa dace by the scale method because scales were small, embedded, and extremely difficult to remove from live specimens. Also, environmental conditions in waters of the Warm Springs area were sufficiently constant that annuli were not readily apparent. Assumed annuli on opercular bones were presumed to be associated with slower growth during the winter. Ages of the eight fish examined ranged from 0+ for a 43-mm-FL individual to 4+ for a 90-mm-FL female (Table 1).

Food Habit

Nine of 30 guts examined were empty and the remainder generally contained few items.

TABLE 3. Estimated number of Moapa dace adults in six tributary streams in the Warm Springs area, Muddy River system, Nevada, 6–14 December 1984, 13–18 June 1986, and 16–22 September 1987.

Stream name	December 1984	Variation in count	June 1986	Variation in count	September 1987	Variation in count
Muddy River	475	±71	1230	±185	1165	±175
Refuge System	370	±56	406	±61	806	±121
Apcar	200	±30	565	±85	475	±72
South Fork	300	±45	185	±28	100	±15
North Fork	15	±2	30	±5	60	±9
Muddy Spring	1450	±218	160	±24	200	±30
Total	2810	±422	2581	±387	2806	±421

[1]Only the upper 130 m of stream was sampled in 1984

but what had been consumed indicated Moapa dace to be omnivorous tending toward carnivory; 75% by composition was invertebrates while 25% was plant material and detritus (Table 2). Among 21 dace guts, oligochaetes represented the largest volume (27.0%) of foodstuffs consumed, followed by filamentous algae (18.5%). In terms of frequency of occurrence filamentous algae occurred in 42.3% of the guts while oligochaetes were in 23.8%. The structure of the pharyngeal teeth also suggests an omnivorous diet; they are strongly hooked but have a well-developed grinding surface (La Rivers 1962). The presence of detritus and gastropods indicates at least some foraging from the benthos, and we observed fish in the field occasionally pecking at substrate. However, the greatest time in foraging is expended on drift feeding (authors, unpublished data), although our data set does not strongly support this observation.

Abundance and Distribution

Moapa dace were more widespread and numerous than had been previously reported (Ono et al. 1984); they were in five headwater tributaries and the upper Muddy River to about 100 m downstream from the Warm Springs Road bridge (Fig. 2). Numbers ranged from about 2600 in 1986 to 2800 in 1984 and 1987. The numerical distribution for the three years suggests movement by the adult population (Table 3). In 1984 the Muddy Spring stream supported about 50% of the population (1450 adults), with only 16% (450 adults) found in the river. In June 1986 we could account for only 7% of the population in the Muddy Spring stream, while almost 50% of the total was in the river. In 1987 the mainstream river again supported most adult Moapa dace (1200). The distribution of adult Moapa dace was patchy and clumped. For example, during the snorkel survey in summer 1986, 79% of the observed dace in the main stem Muddy River were in groups of 10 or more, and 37% were in groups of 30 or more. In tributaries, groups were generally smaller, with 52% of the adults in groups of 10 or more and only 13% in groups of 30 or more.

CONCLUSION

Moapa dace are dependent upon the link between the upper river and its tributaries. The main stem river typically harbors the largest, and presumably the longest-lived, and most fecund fish; yet tributaries are important for reproduction and as larvae and juvenile nursery habitat. Age and growth information suggests that three years is the mean age of fish in the river and that adults in smaller tributaries are one to two years old.

Although the Moapa dace population is more widespread and abundant than previously believed, its existence remains in jeopardy. Widespread movement and obligatory spawning near warm water spring discharge suggest that species survival depends on access to the entire headwater Muddy River system (Warm Springs area), river and tributaries alike. Every effort should be made to preserve all of its remaining habitat.

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